Fermilab

Radiation Physics Note #23

CALCULATION OF SPECIFIC ACTIVITY

FOR A PPA RF CAVITY

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RF cavities from the PPA accelerator are being shipped to Fermilab. It is necessary to calculate the specific activity of these items in order to determine the appropriate Department of Transportation shipping requirements. This note reports a means of calculating the specific activity of such a device using a "line source" approximation. Such a cavity weighs 5000 lb (2.27×10^6 gm) and consist of roughly equal parts Cu, Al, and ferrite by weight and roughly uniformly distributed. The cavity occupies a cylindrical volume approximately 6 ft long and 3 ft in diameter. The specific activity is to be estimated by using a survey meter calibrated in mrad/hr at one foot away from the surface. For computational purposes, the cavity will be assumed to be equivalent to the same material lumped into a rectangular solid of square cross section (t cm square) and 6 ft length.

The densities of the materials are:

$$\rho(\mathrm{Cu}) = 8.92\ \mathrm{gm/cm^3}$$
$$\rho(\mathrm{Al}) = 2.70\ \mathrm{gm/cm^3}$$
$$\rho(\mathrm{Ferrite}) = 5.7\ \mathrm{gm/cm^3}$$

so that the average density $\bar{\rho}$ is 5.77 $\mathrm{g/cm^3}$. This then implies that t, the thickness of the equivalent rectangular solid is:

$$2.27 \times 10^6 = \bar{\rho} \times 182.9\ \mathrm{cm} \times t^2$$
$$t = 46.4\ \mathrm{cm}$$

The radioactivated cavity has had several years to cool down so that the decay of a very few radionuclides dominate the activity. These are listed below for each the 3 target materials (gamma ray emitters only):

Cu: $^{54}\mathrm{Mn}$, $E_\gamma = 0.835$ MeV
Al: $^{22}\mathrm{Na}$, $E_\gamma = 1.27$ MeV
Fe: $^{54}\mathrm{Mn}$, $E_\gamma = 0.835$ MeV

(The oxygen in the ferrite is regarded as negligible in terms of mass compared with the other components.) The average gamma ray energy is then approximately 1 MeV. Surveys of such a cavity presently at Fermilab and installed in the Cooling Ring indicates that the cavity is approximately uniformly activated with local dose rate variations no larger than a factor of three. For simplicity the total activity S of the cavity will be assumed to be uniformly distributed along the length of the cavity. If the photon flux per cm^2, F, is measured at distance R from an infinitesimally thick line source of length L on the perpendicular bisector of the line source, F will be given by:

$$F = \frac{S}{2\pi LR} \mathrm{Tan}^{-1} \frac{L}{2R} \tag{1}$$

where in this case R = 30.48 + 45.72 = 76.2. In the actual case at hand, that of a line source of finite thickness t, buildup and attenuation factors need to be put in. Because most of the contribution to F is due to the portion of the equivalent solid near the perpendicular bisector, it is reasonable to consider all the activity to be emitted from the axis of the source and built up and attenuated by half the thickness of the solid. This also allows for some concentration of the activation near the axis of the beam pipe near the path of the hadron beam. For 1 MeV gamma rays μ, the mass attenuation coefficient has values of 0.0613, 0.0599, and 0.0589 cm^2/gm in Al, Fe, and Cu, respectively representing a linear absorption coefficient of 0.346 cm^{-1} for material of density $\overline{p}$. The quantity $\mu t/2$ then has the value of 8.03. Rewriting Eq. (1) including such factors gives:

$$F = \frac{S}{2\pi LR} B(\mu\frac{t}{2}) e^{-\mu\frac{t}{2}} \mathrm{Tan}^{-1}\frac{L}{2R} \qquad (2)$$

where B is the point source buildup factor. Here values from Radiological Health Handbook are used; for the materials at hand, $B(\mu\frac{t}{2}) = 13.4$. Substituting

$$S = 2.29 \times 10^7 F$$

At 1 MeV, 561 photons/$cm^2 \cdot$sec = 1 mrad/hr so that a reading of 1 mrem/hr implies total source activity of 1.28×10^{10} photons/sec or 346 mCi. The specific activity per mrad/hr survey meter reading is:

$$\frac{\text{specific activity}}{\text{mrad/hr}} = \frac{346 \text{ mCi/mrad/hr}}{2.27 \times 10^6 \text{ g}} = 1.524 \times 10^{-4} \frac{\text{mCi}\cdot\text{hr}}{\text{g}\cdot\text{mrad}} \qquad (3)$$

Thus, a survey meter reading at one foot from the surface of the cavity along the perpendicular bisector of 6.6 mrad/hr corresponds to 0.001 mCi/gm specific activity.

In an actual case, a conservative procedure would be to obtain an average survey meter at one foot from the surface of the cavity over the entire cavity including the beam pipe, multiply the reading by 3 (a safety factor) and using the corrected reading with the factor given in Eq. 3 to obtain the specific activity.